DTU Library

Offshore Wind Power Production in Critical Weather Conditions

Cutululis, Nicolaos Antonio; Litong-Palima, Marisciel; Sørensen, Poul Ejnar

Published in:
Proceedings of EWEA 2012 - European Wind Energy Conference & Exhibition

Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Cutululis, N. A., Litong-Palima, M., & Sørensen, P. E. (2012). Offshore Wind Power Production in Critical Weather Conditions. In *Proceedings of EWEA 2012 - European Wind Energy Conference & Exhibition* European Wind Energy Association (EWEA).

Offshore Wind Power Production in Critical Weather Conditions

Nicolaos A. Cutululis[1], Marisciel Litong-Palima[1], Poul Sørensen[1]

[1]Technical University of Denmark, Denmark
* DTU Wind Energy, Risø Campus, Frederiksbergvej 399, 4000 Roskilde
tel. +4521324965, e-mail: niac@dtu.dk

Abstract

Critical weather conditions, i.e. extreme winds will raise a lot of challenges when it comes to the secure operation of the whole European electric system with the future large scale offshore wind power. This is especially true for Denmark where the target is that wind power should provide 50% of the electricity consumption by 2020.

In the EU funded project TWENTIES, the demonstration #4 STORM MANAGEMENT aims at demonstrating that adequate coordination mechanisms between offshore wind farms and hydro power capacity available in Norway through an existing HVDC link brings viable solutions to securely control the power balance during offshore storm passages. The demonstration will be done on Horns Rev 2 wind farm. In the same project, the impact of a storm front passage over the system security, for the whole Danish system, and with the expected offshore wind power in 2020 will be investigated.

This paper will present the results of up-scaling the impact that a storm front passage will have on the Danish power system in 2020, given that the existing wind turbine storm controller is not replaced. The simulations are done with CorWind and the analysis is focusing on establishing a reference case and quantifying the balancing reserve requirements needed in order to keep the security of the power system.

Introduction

Wind power is currently the most promising renewable technology and is expected to contribute significantly to achieving the “20-20-20” target set by EU - 20% reduction of greenhouse gases and 20% share of renewables by 2020 [1]. The development potential of wind power, especially offshore, is huge. For example, in Denmark only, the target is that wind power will supply approximately 50% of the electricity production by 2020. In order to achieve that, a large amount of offshore wind power, i.e. in the area of 2.5 GW, will be installed in North Sea, in sites that have been selected and published by the Danish Energy Authority [2].

Critical weather conditions, i.e. extreme winds will raise a lot of challenges when it comes to the secure operation of the whole European electric system with the future large scale offshore wind power.

The geographical concentration of wind power, typical for offshore wind farms, leads to increased wind power variability and, in the case of storm front passages it may lead to sudden shut down of whole wind farms.

The TWENTIES project (www.twenties-project.eu) aims at “demonstrating by early 2014 through real life, large scale demonstrations, the benefits and impacts of several critical technologies required to improve the pan-European transmission network, thus giving Europe a capability of responding to the increasing share of renewable in its energy mix by 2020 and beyond while keeping its present level of reliability performance” [3]. One of the demonstrations in Twenties is the Storm Management demonstration. The objective of this demonstration is: “The occurrence of storms will raise new challenges when it comes to secure operation of the whole European electric system with future large scale offshore wind power. With the present control schemes, storms will lead to sudden wind plant shut downs, which in turn is a threat to the whole system security, unless standby reserves are ready to take over power demands under very short notice. The challenge that this demonstration is addressing is to balance the wind power variability, operating the transmission grid securely during such storm conditions. The more specific objectives of the demonstration are to:

- Demonstrate secure power system control during storm passage, using hydro power plants in Norway to balance storm shut down of Horns Rev 2 wind farm in Denmark.
- Use existing forecast portfolio available to the TSO to monitor and plan the down regulation of large scale offshore wind power during storm passages.
- Provide more flexible wind turbine and wind farm control during storms." [3]

Since the demonstration will be done using only one wind farm, the effect of critical weather conditions on the overall offshore wind power production in 2020 will be assessed by terms of simulations. This paper presents this analysis.

Storm control

When wind speed is becoming too strong, wind turbines are shutdown to prevent damage due to extreme mechanical loads. The typical power curve of a modern wind turbine is presented in Fig. 2. The wind turbine will shut down when the average wind speed reaches a certain value denoted V4 in the Fig. 2. When the average wind speed drops below the shutdown value, the wind turbine starts again. To prevent frequent restarts and shutdowns, hysteresis is often applied, so that the wind turbine starts up only when the average wind speed reaches a value V3 lower than the shutdown wind speed.

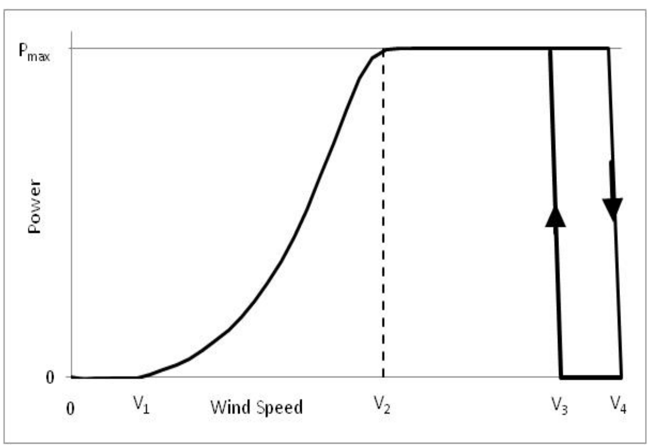

Fig. 1 Typical wind turbine power curve

The typical value for which a wind turbine will initiate shut-down is when the 10-minute average nacelle anemometer wind speed reaches 25 m/s (V4) and they will restart when the measured wind speed drops below 20 m/s (V3).

The wind turbine storm controller was implemented in CorWind and the results where validated against measurements from Horns Rev 2 wind farm. The measurements are from critical weather events that occurred during the period of the project [4]. The comparison between simulations and measurements of the total wind farm production during critical weather events is presented in Figure 2.

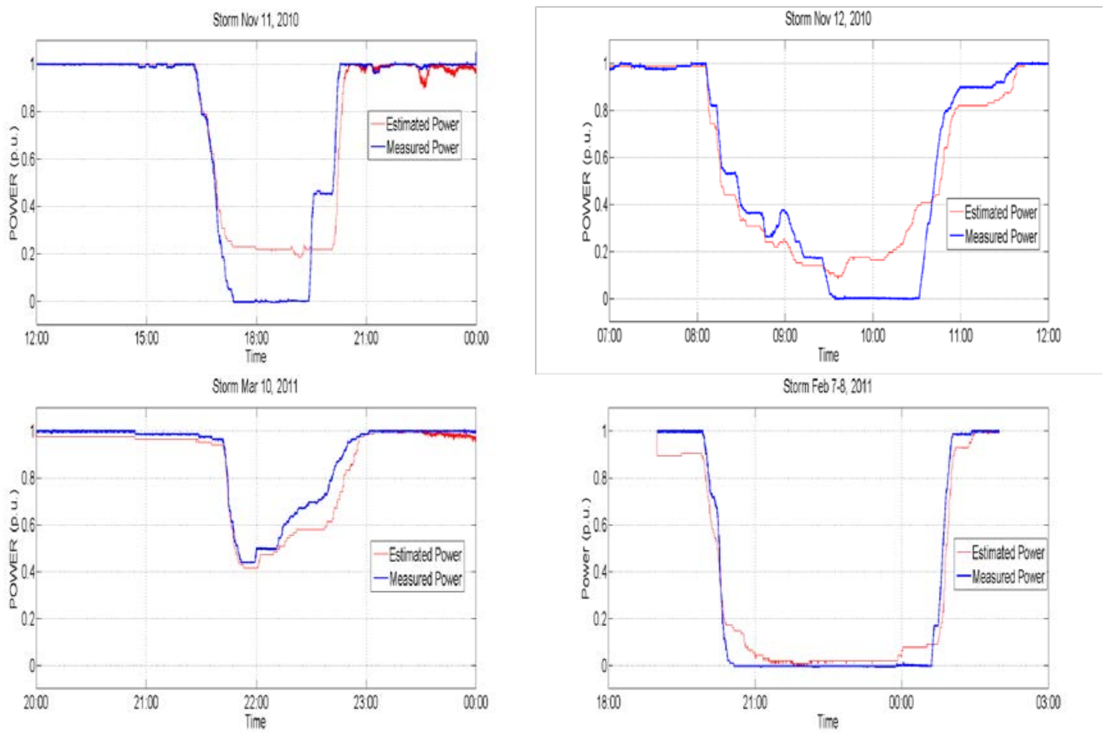

Fig. 2. Simulated vs measured wind farm production during critical weather conditions

The detailed wind farm model, i.e. individual wind turbines were simulated in the cases presented above. This can be done when the scope is to simulate one or few large offshore wind farms. When looking at larger areas, with an extensive number of wind farms – comprising of hundreds of wind turbines – the detailed simulation might prove extremely time expensive. For that, an equivalent wind farm power curve that includes storm control was developed. The result of this analysis is presented in Figure 3

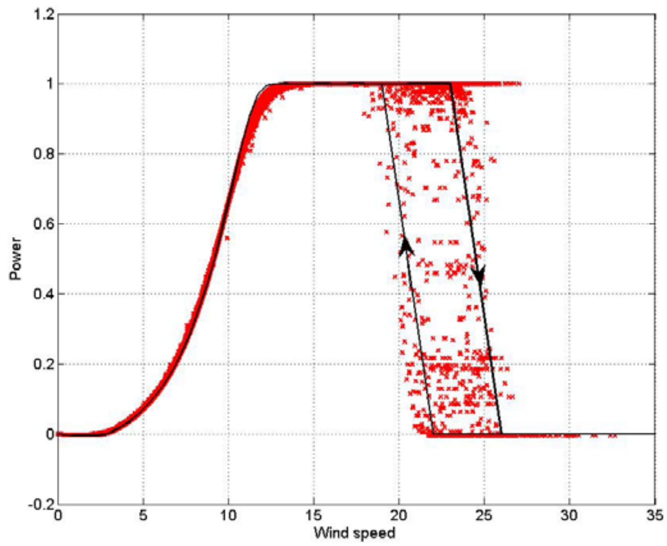

Fig.,3 Aggregated wind farm power curve

Wind power development scenario

The analysis presented in this paper aims at quantifying the effect of critical weather conditions on the stable power system operation in 2020, with large amounts of offshore wind power. The assessment is done for Denmark. The offshore wind power development scenario for 2020 in Denmark was done based on the offshore wind farms sites published by the Danish Energy Authority and other public sources. Two scenarios were considered: a conservative one, named baseline scenario and am optimistic one, named high scenario.

The detailed wind farms considered in the 2020 scenarios for Denmark are presented in Table 1

Table 1. Offshore wind farms in 2020 in Denmark - scenarios

Country	Scenario		Coordinates	
	Base	High	Lat	Lon
Denmark				
Anholt	400	400	56.604	11.209
Avedøre Holme	11	11	55.601	12.464
Frederikshavn	11	11	57.443	10.562
Horns Rev A HR3	200	200	55.647	7.791
Horns Rev A HR4	0	200	55.71	7.849
Horns Rev A HR5	0	200	55.789	7.88
Horns Rev 1	160	160	55.486	7.84
Horns Rev 2	209	209	55.6	7.582
Kriegers Flak A K2	200	200	55.05	12.984
Kriegers Flak A K3	200	200	54.994	12.822

Kriegers Flak A K4	200	200	55.005	13.068
Kriegers Flak B K1	200	200	55.077	12.874
Middelgrunden	40	40	55.689	12.668
NearshoreLAB	36	36	57.457	10.637
Nysted (Rødsand 1)	166	166	54.549	11.714
Ringkøbing Fjord B RK 3	200	200	56.018	7.71
Rødsand 2	207	207	54.555	11.548
Rønland	17	17	56.662	8.22
Samsø	23	23	55.723	10.584
Sprogø	21	21	55.343	10.958
Store Middelgrund MG1	200	200	56.5	12.095
Tunø Knob	5	5	55.968	10.355
Vindeby	5	5	54.969	11.129
Århus Bugt	100	100	56	10.48

The geographical distributions of those wind farms is shown in Fig. 4

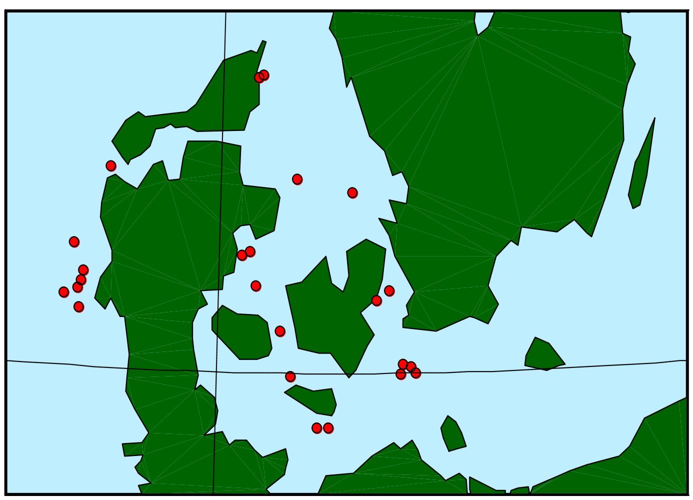

Fig. 4. Offshore wind farms in Denmark in 2020

Table 2. Critical weather periods

2001	01/01/2001	**2008**	21/03/2008
2005	02/01/2005		13/08/2008
2007	01/01/2007		08/11/2008
	08/01/2007	**2009**	11/06/2009
	18/03/2007		03/10/2009
	27/06/2007	**2010**	11/11/2010
	08/11/2007		07/02/2010
2008	25/01/2008	**2011**	10/03/2011
	27/02/2008		

Simulations

In order to have a statistically valid image of the reserves requirements, a number of critical weather events were simulated. The list of those events is given in Table 2.

Each event was simulated with five different random seeds for the stochastic part [5]. Since the scope of the analysis is to quantify the impact of critical weather conditions on the stable operation of the power system, the time scale is set to 5 min.

The results were quantified in terms of reserve requirements. The definition of reserve requirements applied in this paper is quite similar to the definition of regulation applied by Parson et al. [6]. The intention is to quantify the difference between the instantaneous power and the mean value that are dealt with as ramping. Since the reserves must be allocated in advance, the positive reserve requirement is defined as the difference between the initial mean value and the minimum value in the next period. Formally, the reserve requirements are defined as, see also Fig. 5:

$$P_{\mathrm{ramp}}(n) = P_{\mathrm{mean}}(n) - P_{\min}(n+1) .$$

Note that with this definition, positive reserves means decreasing wind power that requires positive reserves form other power plants.

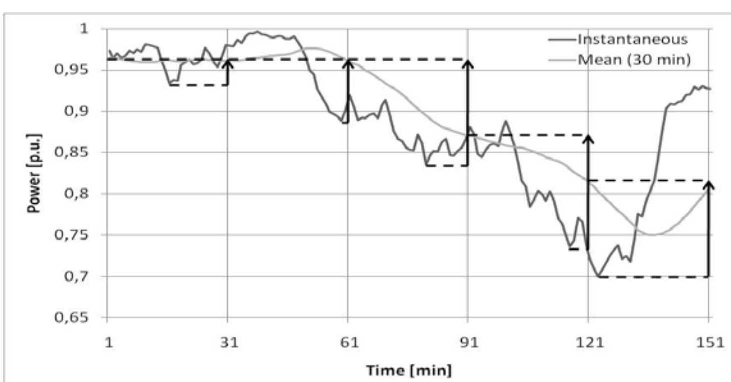

Fig. 5 Definition of reserves

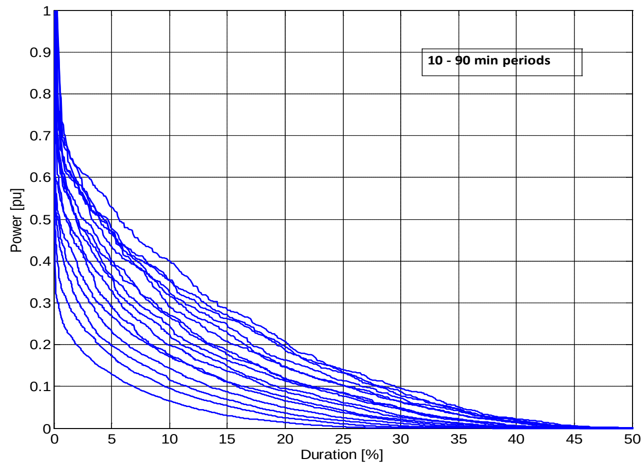

Fig. 6. Duration curves of reserves for different periods

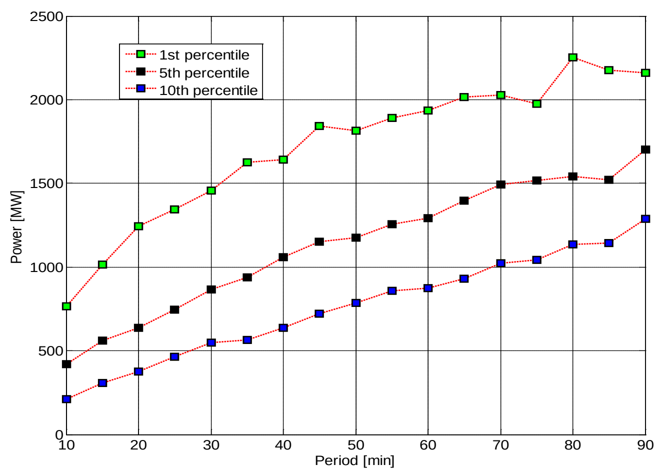

Fig. 7 the 1st, 5th and 10th percentile vs time

Using this definition, the reserves were calculated for different periods, i.e. from 10 to 90 min, in 5 min steps. The duration curves for each of the considered periods are given in Fig. 6

It is seen that the reserve requirements are increasing with the time period. In this context, it is of interest to quantify the “worst-case” reserves, namely the 1st percentile. This, together with the 5th and 10th percentile is shown in Fig. 7. The results show that, in the worst case, around 1500 MW of wind power can be lost in 30 minutes, with this number going up to 2000 MW lost in one hour. This can pose serious challenges to the stable operation of the Danish power system. For the 5^{th} and 10^{th} percentile, the numbers are smaller, but still large.

Conclusions

Today, critical weather conditions, with very high wind speeds, lead to sudden loss of wind power due to the way the wind turbines operate. When the wind speed exceeds a certain value, the wind turbine stops in order to protect itself. This is called storm control. The impact of critical weather periods on the stable operation of the power system was investigated. The simulations were done with the estimated wind power development scenario for offshore wind power in Denmark. The results show that, with the present storm controller, during critical weather conditions periods, significant amounts of wind power production will be lost in periods of time ranging from ten minutes to over an hour. Those amounts, in the worst case, can go up to 50% of installed capacity in 30 minutes and around 70% in an hour. That means that the reserves requirements – generators capable of replacing the lost wind power production fast – are very significant. Further work will investigate the impact of the new storm controller, developed in the TWENTIES project, on the reserve requirements.

Acknowledgments

The works and developments required for the elaboration of this paper/article have been carried out partially within TWENTIES project (www.twenties-project.eu) which belongs to the Seventh Framework Program funded by European Commission under project no. ENER/FP7EN/249812/"TWENTIES".

References

[1] 20 20 by 2020. Europe's climate change opportunity COMMISSION OF THE EUROPEAN COMMUNITIES. Brussels, 23.1.2008. COM(2008) 30 final.

[2] Future offshore wind power sites – 2025 (in Danish). Danish Energy Agency, Ministry of Climate and Energy, April

[3] www.twenties-project.eu

[4] Nicolaos A. Cutululis, Nina Detlefsen, Poul Sørensen, Offshore wind power prediction in critical weather conditions, 10^{th} International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants, Aarhus (DK), 25-26 Oct 2011.

[5] Sørensen, Poul; Pinson, Pierre ; Cutululis, Nicolaos Antonio ; Madsen, Henrik ; Jensen, Leo Enrico ; Hjerrild, Jesper ; Heyman Donovan, Martin ; Runge Kristoffersen, Jesper ; Vigueras-Rodríguez, Antonio, Power fluctuations from large wind farms - Final report, Risø-R-1711(EN);

[6] B. Parson, M. Milligan, B. Zavadil, D. Brooks, B. Kirby, K. Dragoon, J. Caldwell, "Grid Impacts of Wind Power: A summary of recent studies in the United States," Wind Energy , vol. 7, Apr./Jun. 2004, pp 87-108.